THERMAL CONSTRAINTS FROM SIDEROPHILE TRACE ELEMENTS IN ACAPULCOITE-LODRANITE METALS.

J. S. Herrin[1], D. W. Mittlefehldt[1], M. Humayun[2], [1]NASA/Johnson Space Center , Houston, TX, USA (jason.s.herrin1@jsc.nasa.gov), [2]National High Magnetic Field Laboratory and Dept. of Geological Sciences, Florida State University, Tallahassee, FL 32310, USA.

Introduction: A fundamental process in the formation of differentiated bodies is the segregation of metal-sulfide and silicate phases, leading to the formation of a metallic core. The only known direct record of this process is preserved in some primitive achondrites, such as the acapulcoite-lodranites. Meteorites of this clan are the products of thermal metamorphism of a chondritic parent. Most acapulcoites have experienced significant partial melting of the metal-sulfide system but not of silicates, while lodranites have experienced partial melting and melt extraction of both. The clan has experienced a continuum of temperatures relevant to the onset of metal mobility in asteroidal bodies and thus could yield insight into the earliest stages of core formation. Acapulcoite GRA 98028 contains relict chondrules, high modal sulfide/metal, has the lowest 2-pyroxene closure temperature, and represents the least metamorphosed state of the parent body among the samples examined. Comparison of the metal-sulfide component of other clan members to GRA 98028 can give an idea of the effects of metamorphism.

Methods: We have analyzed trace elements in metallic phases in eight acapulcoite-lodranites from the U.S. Antarctic Meteorite Collection by LA-ICP-MS at the ICP-MS facility of the National High Magnetic Field Laboratory/Florida State University for major and trace siderophile elements using the methodology of [1] and obtaining similar analytical precision. Metal, sulfide, and silicate phases in these samples had been characterized previously by EPMA at NASA Johnson Space Center.

Results: Siderophile element concentrations in acapulcoite-lodranite metals are generally higher than in bulk chondrite or H chondrite metals. Variability in the concentration of incompatible siderophile elements (ISE), those that partition most readily into the melt phase (e.g. As, Au, Pd), relative to compatible siderophile elements (CSE), those that partition most readily into the solid phase (e.g. Pt, Ir, Re, Os), is observed among metals of different samples. Samples with ISE/CSE both higher and lower than H chondrite were observed (Fig 1). Metal in all samples is predominantly kamacite but Ni-rich phases are also present, chiefly plessite, with average Ni content of metals from different samples ranging 6-11 wt%, and 14.5 wt% for sample MAC 88177. The representative metal composition of each sample was taken to be the average of several analyses.

Discussion: In general, the observed ISE/CSE of metals of different samples demonstrate relationships with textural and mineralogic indications of metamorphic grade, a relationship that suggests progressive melt extraction with increased temperature. The fact that some samples contain little or no sulfide phase (e.g. EET 84302) provides further evidence that metal-sulfide melt extraction was an efficient process accompanying metamorphism. We modeled the evolution of siderophile trace elements in metals during 0.1 wt% incremental metal-sulfide batch melt extraction using average GRA 98028 metal as a starting composition. Since the S content of the melt phase exhibits primary control over the partitioning behavior of many elements [2], predicted D values for a range of melt S contents were employed. By comparing the resultant solid phase compositions with those measured in actual metals, the extent of melt extraction and the S content of equilibrium melt were estimated (Fig 2).
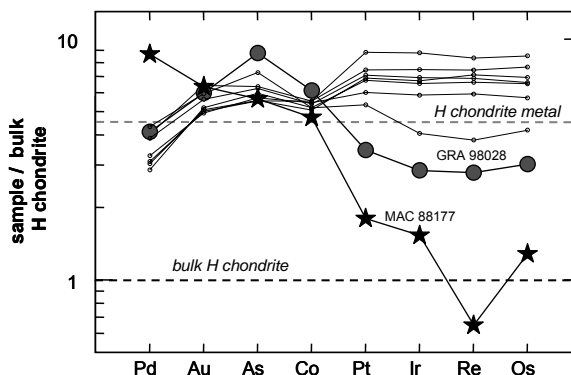

Figure 1: Average metallic siderophile element abundances in analyzed samples normalized to bulk H chondrite in order of increasing $D^{solid-liquid}$ at X_S=0.35. Primitive GRA 98028 and anomalous MAC 88177 are indicated. Model H chondrite metal composition estimated from bulk.

In the Fe-FeS system, S content of liquidus melts decreases with increasing temperature above the eutectic, so estimates of melt S content provide an indirect means of estimating equilibrium temperature. Correlation between estimated melt S contents and 2-pyroxene closure temperatures of different samples (Fig 3) seems to confirm that temperatures of metal-sulfide melt extraction can be estimated from siderophile trace element compositions of residual metals. All samples besides GRA 98028 were probably heated above the Fe-Ni-S cotectic, especially when we consider that pyroxene blocking temperatures are likely lower than peak metamorphic temperatures. There is little correla-

tion, however, between pyroxene temperatures (or temperatures inferred from estimated X_S) and the estimated amount of melt extracted from each sample, suggesting that the efficiency of metal-sulfide melt extraction in an asteroid is dependent on other parameters besides temperature.
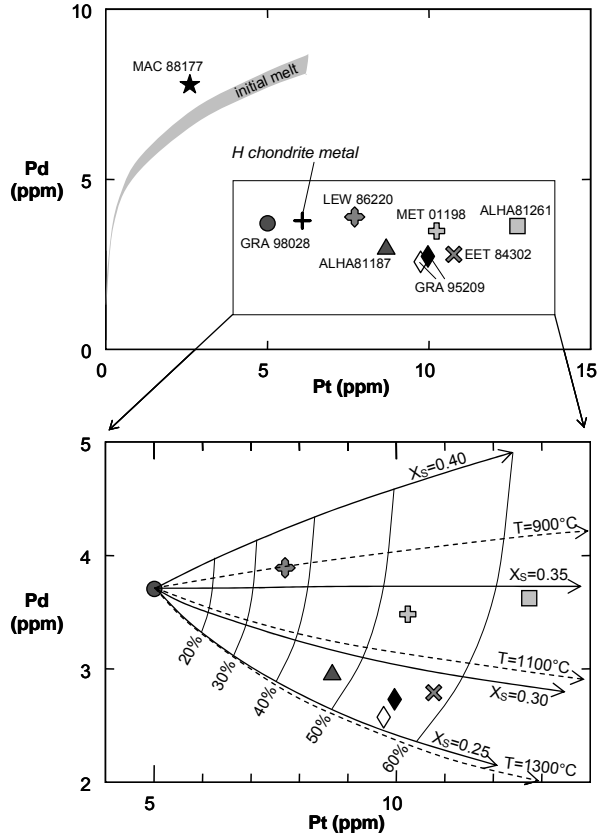

Figure 2: Solid phase Pt vs. Pd evolution lines (inset) for melt extraction from metals (expressed as % of original mass) at different liquid phase S contents (X_S = mole fraction S) with GRA 98028 metal as a starting composition similar to model H chondrite metal. Temperature lines were estimated from relationship in Fig 3. Metal of MAC 88177 (top) resembles a low degree partial melt from a fertile source region.

Anomalous sample MAC 88177 is a basalt-depleted lodranite with a high 2-pyroxene closure temperature (1200°C), low metal content (modal metal + troilite = 4%), high modal sulfide/metal (4:1), abundant Ni-rich metal with high ISE/CSE ratios, and high Fe# of ferromagnesian silicates (opx Fe#11.4). The metals of this sample cannot be a residuum derived from GRA 98028 or an H chondrite parent. Instead, the metal-sulfide component in this sample resembles a low-degree partial melt derived from some fertile portion of the parent asteroid. It is unclear whether the apparently complete removal of primary metal from this sample preceded or resulted from this influx of S-rich melts. Among the two samples yielding the highest 2-pyroxene temperatures, GRA 95209 contains large contiguous sheets of metal [3] while MAC 88177

has apparently lost all of its original metal. These features are absent from any lower temperature samples, suggesting that segregation of metal *en masse* was an efficient process only in higher temperature regions, while metal migration elsewhere was predominantly that of partial melts.
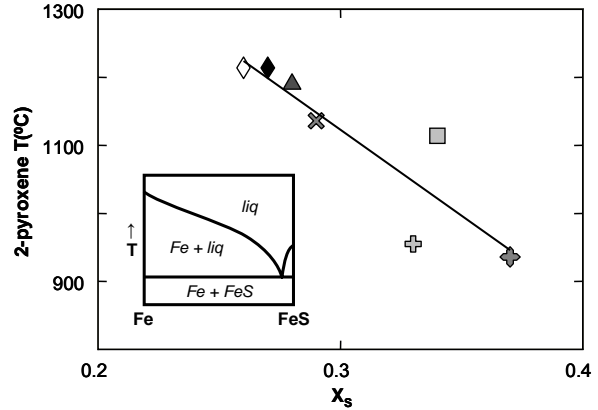

Figure 3: Relationship between 2-pyroxene closure temperatures and S content of melts in equilibrium with solid metals estimated from Pt vs. Pd systematics. Symbols denote samples as in Fig 2. Fe-FeS binary phase diagram (inset) showing lower S liquidus with increased T.

Other considerations: A major limitation of this approach is that melt extraction is modeled as an isothermal process, while it is likely that actual melt extraction took place over a range of temperatures. Nevertheless, it can provide a useful first-order approximation of the average conditions of melt extraction. It is difficult to determine whether GRA 98028 is representative of an actual protolith. Metals in this sample are enriched in ISE/CSE relative to bulk H chondrite, and the sample has a higher modal sulfide/metal ratio (5:2 compared with 1:3 [4]). If H chondrite metals are instead taken as a starting composition, estimates of X_S are 0.01-0.04 lower and melt extraction estimates decrease by ~10%. The influence of C and P on partitioning behavior were not considered. The similarity in Co concentrations between acapulcoite-lodranite and H chondrite metals, as well as the strong correlation between CSE concentrations and CSE/ISE ratios among different acapulcoite-lodranites, indicates that metal production and oxidation can be considered to have had only minor effect during metamorphism of the parent asteroid.

References: [1] Campbell A. J. *et al.* (2002) *GCA, 66,* 647-660. [2] Chabot N. L. and Jones J. H. (2003) *M&PS, 38,* 1425-1436. [3] McCoy T. J. *et al.* (2006) *GCA, in press.* [4] McSween Jr. H. Y. *et al.* (1991) *Icarus, 90,* 107-116.